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SEA-LEVEL INDICATORS FROM A HOLOCENE, TIDE-DOMINATED COASTAL SUCCESSION, PORT PIRIE, SOUTH AUSTRALIA

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Summary

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Peritidal Holocene sediments at Port Pirie in the northern Spencer Gulf of South Australia contain several indicators of sea-level change over the last 7,000 years BP. The elevations of present subtidal, intertidal and supratidal environments and corresponding sediment facies were surveyed in order to establish critical boundaries relative to the tidal spectrum. The subtidal *Posidonia* facies occurs at or below mean low water spring (MLWS) tide; intertidal sandflat, mangrove and samphire facies occur over specific intervals between MLWS tide and mean high water spring (MHWS) tide. Each facies is clearly identifiable in the subsurface, with intertidal sandflat facies particularly characterised by *in situ* articulated bivalves *Anapella cycladea* and *Katelysia scalarina* or *K. peronii*. A combination of several palaeosea-level indicators from different tidal facies best defines local sea-level change over the millennial timescale.

KEY WORDS: Holocene sea level indicators, tidal zonation, prograding coastal sequence, facies boundaries.

Introduction

Tide-dominated coastlines commonly generate prograding coastal sequences with excellent preservation of intertidal and shallow subtidal sedimentary facies (Belperio *et al.* 1988; de Boer *et al.* 1988; Fletcher *et al.* 1993). Such sequences can reveal high-resolution records of past sedimentation often containing a variety of palaeosea-level indicators (Terwindt 1988). A thorough understanding of the relationships of present indicators and sea level, or inundation level, is required if correct interpretations of past relative sea levels are to be achieved. With critical appraisal of the present-day distribution of intertidal facies, flora and fauna, palaeosea level history from subsurface stratigraphy can be more confidently interpreted.

The northern Spencer Gulf, South Australia (Fig. 1), provides an excellent example of a wide, prograding coastal sequence in a mesotidal environment with an identifiable zonation of Holocene coastal depositional environments. A number of coastal studies has been conducted previously in this area (Firman 1965; Burne 1982; Burne & Colwell 1982; Belperio *et al.* 1984a, b, 1988; Gostin *et al.* 1984, 1988; Norrish *et al.* 1986). In particular, Burne (1982) identified several important palaeosea-level indicators from beach ridges, the top of the subtidal *Posidonia* seagrass facies and base of the intertidal sandflat facies, and Belperio *et al.* (1984b) demonstrated the presence of a well-defined boundary between *Posidonia* seagrass and intertidal sandflat facies. Related stratigraphic studies in nearby Gulf St Vincent include those by Cann & Gostin (1985), Belperio *et al.* (1986, 1988), and Belperio (1993, 1995). At Port Adelaide in Gulf St Vincent, Belperio (1993) confirmed that the boundary between the intertidal sandflat and mangrove facies was a reliable palaeosea-level indicator. From all these studies, it is apparent that there are local and regional differences in the reliability and distribution of various sea-level indicators. This paper provides a critical appraisal of the different palaeosea-level indicators in a mesotidal environment.

The wide prograding sedimentary sequence of the northern Spencer Gulf region, which forms the apex of a large relatively shallow inverse (or negative) estuary, is a direct response to the modern coastal environment. Warm temperatures and low rainfall in the region promote high rates of evaporation and salinities which are often higher than average for seawater, in excess of 40‰ and as much as 48‰ (Bye 1981; Nunes & Lennon 1986). Seawater temperatures for the northern gulf vary typically between 12° and 24° C (Nunes & Lennon 1986). The tides are mostly semi-diurnal, with spring and neap tidal ranges at Port Pirie of 3.5 m and 0.4 m, respectively. Due to the length of the gulf and relatively slow mean sea-level oscillations, wind stress can further increase the astronomical tide

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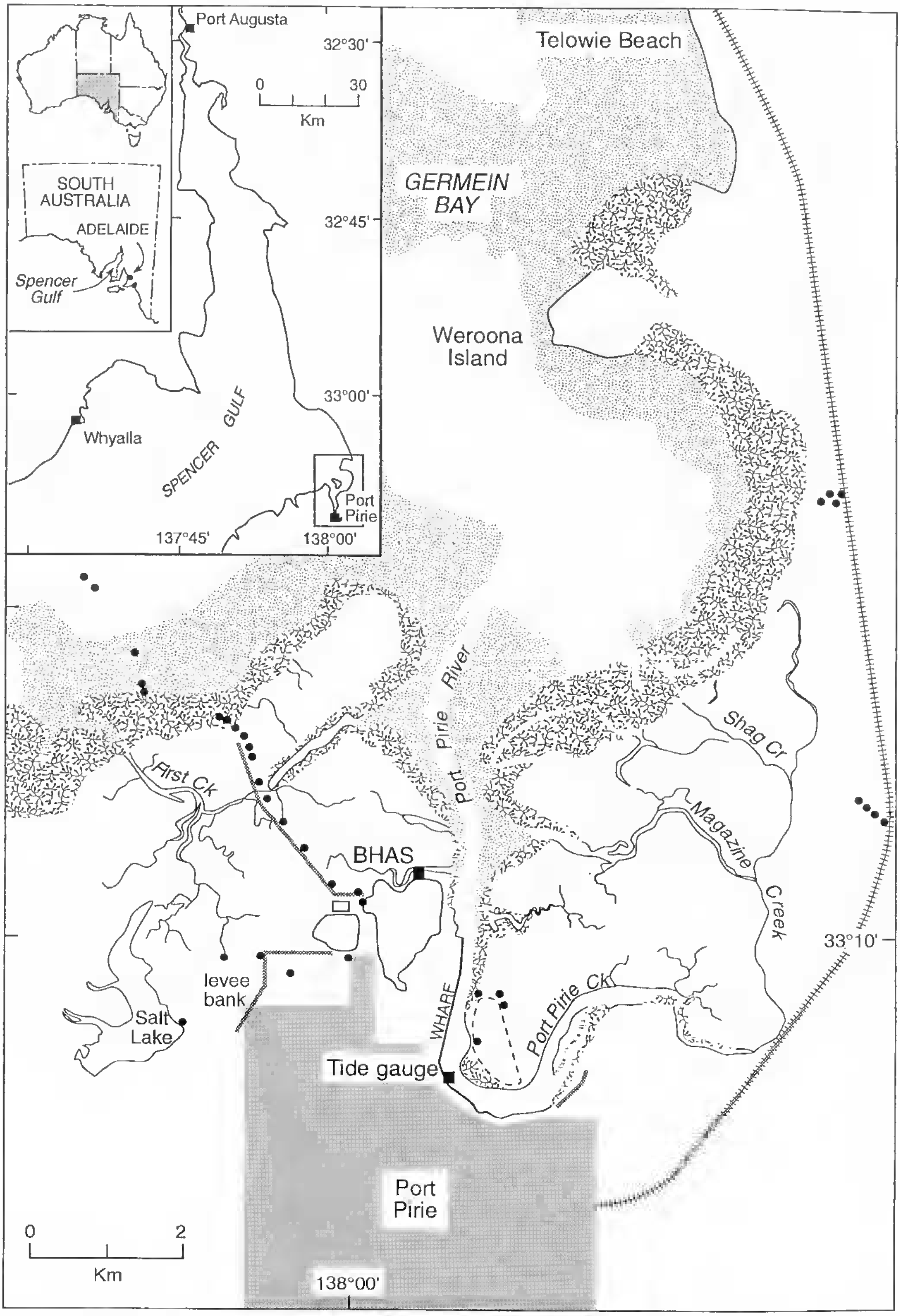

Fig. 1. Location diagram of the study area in the upper Spencer Gulf, South Australia, showing the Port Pirie coastal zone, sampling sites marked by infilled circles, the tide gauge and Broken Hill Associated Smelters (BHAS).

significantly. In Spencer Gulf and much of the southern coast of Australia (Nunes & Lennon 1986), there is a large spring-neap tidal modulation due to the nearly equal lunar and solar semidiurnal constituents causing a dodge tide once every fortnight when little tidal variation occurs. Schluter *et al.* (1995) have postulated that this similar amplitude of the major semi-diurnal tidal constituents gives rise to particular shallow water tidal interactions in the upper gulf, which promote samphire and mangrove colonisation.

Given the prograding tidal sequence and the close proximity of a tide gauge with reliable long-term records at Port Pirie, this study was undertaken to determine the elevations of coastal sedimentary zones relative to modern sea level and to identify appropriate modern sediments as analogues of subsurface Holocene sedimentary facies. This approach provides an opportunity to identify the most reliable palaeosea-level indicators in a mesotidal environment; and to develop a methodology for subsequent studies of relative land/sea movements at sites where historic tidal data exist. The study is unique in that it highlights a number of sedimentary facies, surveyed relative to modern sea level, and identifies critical equivalent indicators in the geological record. It does not depend on one indicator in isolation, but uses a suite of subtidal to supratidal indicators to identify sea-level change.

Methods

It was necessary to survey the modern coastal environments in detail to establish elevation differences of the tidal zones relative to local tidal datum. This was done using both laser and automatic spirit levelling instruments. The first had an error of less than 1 cm over 200 m, and measurements were kept to within 400 m (i.e. ± 0.02 m). Using spirit levelling, the distance between each reading was less than 100 m, which generally kept vertical measurement errors to less than ± 0.01 m. Land-based sites within the sandflat, mangrove and samphire zones were surveyed to third-order Australian Height Datum (AHD) benchmarks. The surveying was conducted mostly in the Port Pirie coastal vicinity as well as further to the northeast within the Telowie Beach coastal region, in order to access all of the modern-day tidal settings (Fig. 1). The present-day levels of the seagrass and sandflat zones at Port Pirie were measured from water levels relative to the Port Pirie tide gauge. At Port Pirie, zero tidal datum (TD) is correlated with the lowest astronomical tide and related to AHD using a correction of 1.933 m (surveyed 17.03.1983: South Australia Ports Authority). Sea-level indicators including seagrass, shell and mangrove remains within and at the top of each tidal zone were identified and recorded for later comparison with subsurface equivalents.

In order to establish and sample the subsurface stratigraphy, a total of thirty-five sites was selected within the broad coastal flats of Port Pirie (Fig. 1). A vibrocorer was used to obtain cores 75 mm in diameter and up to 4 m in depth. All of the vibrocores were corrected for sediment compaction by recording penetration depth versus core recovery length and applying a correction factor to the thickness of the sediments. Coring peripheral to and within mangrove woodlands was carried out using a peat auger. A back-hoe was used to excavate sediments in the supratidal region. Using this method, no correction for sampling compaction was necessary. Surface and subsurface elevations in land-based cores and excavations were surveyed to AHD. Marine-based cores were surveyed to TD and taken within a few kilometres of the tide gauge to reduce the effects of tidal lag and meteorological conditions. Samples were taken back to the laboratory, where the sediments were logged with particular attention being given to the elevations of facies boundaries and the presence of sea-level indicators.

Modern depositional tidal environments in the Port Pirie area

The coastal environment adjacent to Port Pirie (Fig. 2) is a tidally-dominated lowland. Subtidal, intertidal and supratidal zones were distinguished by the extent of marine influence or exposure and by their vegetation assemblages and sedimentary facies. Broad, shallow subtidal seagrass meadows pass laterally shoreward into intertidal sandflats, mangrove woodlands, samphire-algal marshes and supratidal evaporite flat environments. This association of peritidal environments and their vegetation zones has, to a large extent, controlled the successive development of the coastal plain around Port Pirie. A schematic summary of the tidal zones, associated vegetation and their relationships to elevation or inundation levels is given in Figure 3.

The subtidal zone

In the broad, shallow-marine environment northwest of Port Pirie township, seagrass meadows composed largely of *Posidonia australis* grow from around mean low water spring (MLWS) tide level (zero TD) to 10 m below TD (Figs 3, 4). *Posidonia australis* can only survive limited periods of emergence so that, at its upper growth limit, it is generally patchy and restricted to below 0.25 m TD. At depths below 4 m TD, *Posidonia sinuosa* dominates the seagrass assemblage. *Posidonia* leaf

sheaths and rhizomes are resistant to decomposition, and seagrass fibres become incorporated into and bind sediments. A highly distinctive sediment facies results, producing calcareous mud and sand bound by masses of pale cellulose fibre. High sediment production and the binding and baffling action of seagrass contribute to the rapid accumulation of sediments in this environment.

The intertidal zone

The region extending from MLWS tide to mean high water spring (MHWS) tide is defined as the intertidal zone (Fig. 3). This zone is characterised by periodic emergence and inundation during neap to spring high tides. At their most seaward boundary, broad sandflats have developed upon which some seagrasses can grow above MLWS. *Posidonia australis* struggles to survive and is replaced by *Zostera muelleri*. Further shoreward, bare sandflats are dominant. These sandflats are host to numerous epibenthic organisms including the intertidal molluscs *Batillaria* sp., *Veneridae* sp., *Tellina* sp., *Clanculus* sp., *Anapella cycladae* and *Katelysia scalarina* or *K. peronii* and foraminifera that live on and beneath the sandflat surface. These organisms occasionally accumulate in shallow tidal channels.

Intertidal sandflats are replaced by mangrove woodlands above 1.32 m TD. Only one species of mangrove, *Avicennia marina* var. *resinifera*, has been recorded growing in South Australia (Butler *et al.* 1977; Gostin *et al.* 1984; Cann & Gostin 1985) (Fig. 5). Around Port Pirie, mangroves have formed dense

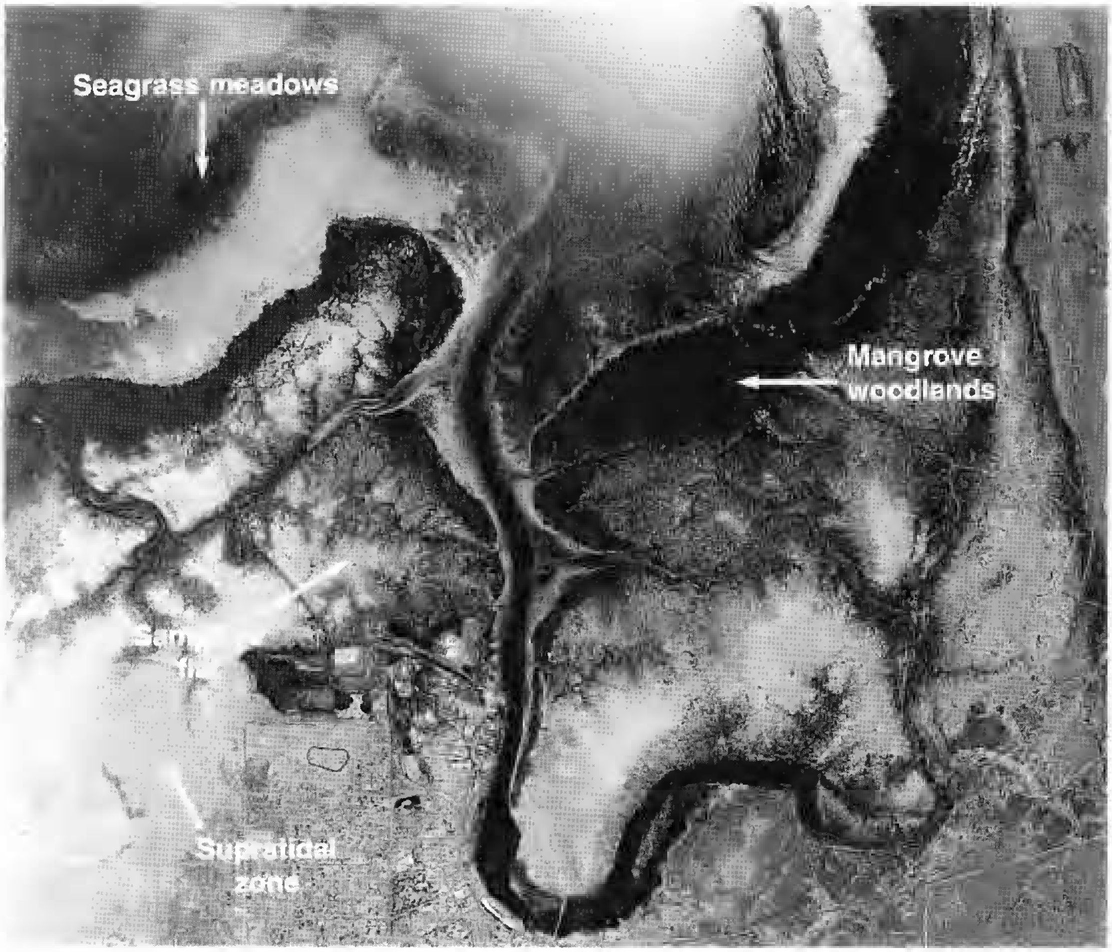

Fig. 2. Aerial photograph of the Port Pirie coastal zone. The subtidal and intertidal sandflats have been colonised by seagrasses (seagrass meadows). Further inshore, mangroves form dense woodlands along the coastal margin and grow along dendritic tidal channels. Samphire communities occur more landward in the intertidal to supratidal zone. In the supratidal zone, the vegetation cover is sparse in between broad expanses of saltpans. The photograph covers an area approximately 10 km x 10 km. The aerial photograph as been reproduced with the permission of the Department of Natural Resources, South Australia, Mapland, telephone (08) 8226 4946.

communities within clearly defined tidal limits. While the lower limit of mangroves is close to mean sea level (1.75 m TD at Port Pirie), their actual lower limit, 1.32 m TD at Port Pirie, can be significantly different. Their distribution is controlled fundamentally by their root system since the vertically protruding pneumatophores require both exposure to air and flushing of precipitated salts (Chapman 1975). A mangrove-algal association occurs at seaward levels of mangrove growth and along exposed tidal channels. Cyanobacterial mats also extend on to wide sandflats and into samphire areas in intertidal and supratidal zones. Numerous other organisms are associated with mangrove woodlands, including the small mud crab, *Helice haswellianus*, which burrows into the substrate and promotes oxidation of the upper sediments. Gastropods, bivalves, polychaetes, decapods and other crustaceans, foraminifera and diatoms also occupy this zone.

Landward of the mangroves at elevations above 2.6 m TD, are broad, flat, gently undulating plains upon which samphire-algal communities grow (Fig. 6). *Sarcocornia quinqueflora*, *Sclerostegia arbuscula*, *Halosarcia halocnemoides* and *Suaeda australis* are the main samphire communities present in the Port Pirie environment, followed by minor occurrences of *Maireana oppositifolia* and

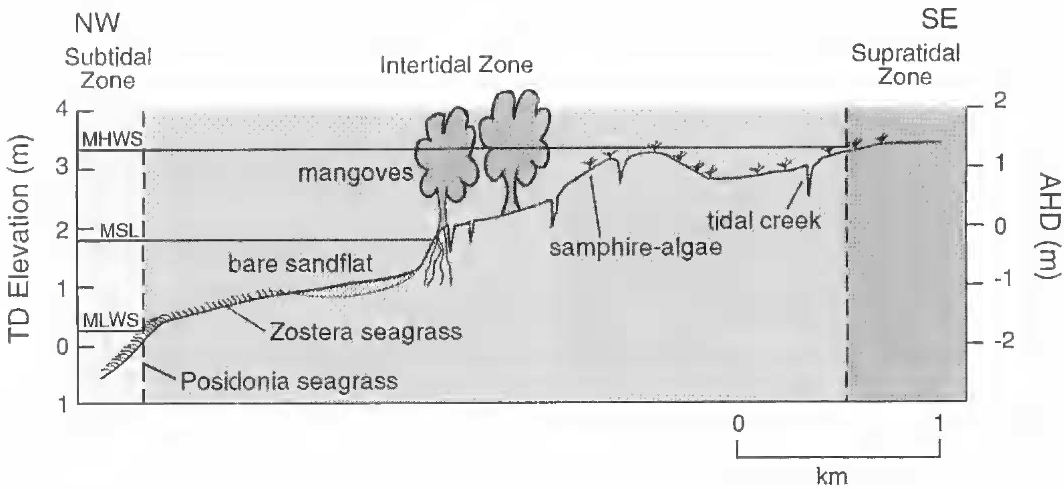

Fig. 3. Present tidal and vegetation zonation along core transect relative to the Port Pirie tidal datum (TD) and Australian Height Datum (AHD). MLWS - mean low water spring tide; MSL - mean sea level; MHWS - mean high water spring tide.

Fig. 4. Shallowly submerged seagrass meadow of *Posidonia australis* in the subtidal zone photographed during low tide. Width of field approximately 3 m.

Fig. 5. Landward intertidal mangrove margin with intertidal samphire communities. Only one species of mangrove, *Avicennia marina* var. *resinifera*, grows in this southern temperate latitude. Dieback of mature trees along the landward margin can be observed, which generally indicates marine regression. The dead mangrove in left centre of the photograph is approximately 1.2 m tall.

Halosarcia indica toward the supratidal margin.

The supratidal zone

Above MHWS tide elevation (3.2 m TD), the supratidal zone (Fig. 3) is flooded on only the few occasions when either high or king tides combine with storm surge activity, predominantly from the southwest, or during and shortly after extended periods of rainfall. Consequently, this zone is dominated by evaporative processes and their associated sediments. In some ponded areas, algal mats are well established and form cyanobacteria flats. Although this region consists mainly of bare, poorly draining saline and gypsiferous flats, some samphires and saltbushes survive (Fig. 7). Of these, *Halosarcia halocnemoides*, *Atriplex paludosa*, *Halosarcia indica* and *Atriplex vesicaria* are most abundant. Within this zone, variations in elevation are created by aeolian deflation and formation of gypsiferous dunes between remnant tidal channels.

Fig. 6. Intertidal samphire zone including *Sarcocornia quinqueflora*, *Sclerostegia arbuscula*, *Halosarcia halocnemoides* and *Suaeda australis*. The mangrove in the right foreground is approximately 2 m high and the samphire bushes are up to 30 cm in height.

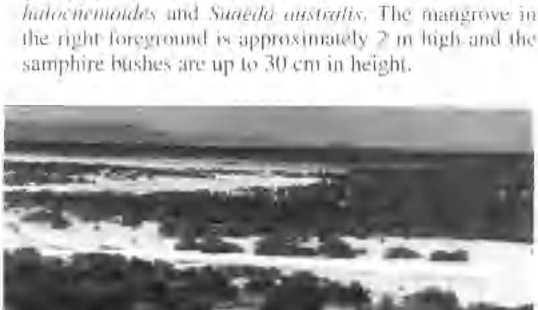

Fig. 7. Supratidal samphire zone including occasional *Halosarcia halocnemoides*, *Atriplex paludosa*, *Halosarcia indica* and *Atriplex vesicaria*, and bare expanses of saltflat. The samphire species are up to 30 cm in height.

Lunettes have also formed on the leeward margins of sabkha flats or salt lakes.

The distribution of coastal environments around Port Pirie is shown in Figure 8. Six distinctive tidal zones transecting the coast have been identified. From seaward to landward, these are: i) subtidal seagrass meadows (not shown in figure), ii) low intertidal bare or *Zostera*-covered sandflats, iii) intertidal mangrove woodlands, iv) high intertidal samphire-algal marshes, v) supratidal evaporative flats, and vi) supratidal and extratidal clay and gypseous dunes and lunettes. Aerial photographic interpretation of the mangrove woodland reveals that only minor change in its distribution is apparent for the last 40 years or so (1957-1993). Mangroves have prograded seaward into intertidal seagrass/sandflat areas on the northwest peninsula of the Port Pirie River, between First and Second Creek and along the margins of the Port Pirie River itself. This is in contrast to rapid seaward mangrove colonisation that has occurred at Port Gawler (Cann & Gostin 1985) and landward colonisation in the Port Adelaide region (Burton 1982; Belperio 1993).

Evidence of depositional tidal sediments in the subsurface

Much of the sedimentary stratigraphy at Port Pirie represents aggradation and progradation of sediments in peritidal environments since the near stabilisation and slight fall in sea level from 7,000 years BP to present (Belperio 1995). Holocene sediments and Pleistocene alluvial sediments of the Pooraka Formation underlie most of the area, forming an undulating boundary with the overlying tidal sequence. In some places, the upper sections of the Pooraka Formation show evidence of being altered or gleyed by marine porewaters. The coastal sediments record an upward change in sediment facies that corresponds with the lateral change in the tidal zones.

The subtidal *Posidonia* facies is the most extensive Holocene tidal facies in the region. It consists of mostly grey, poorly sorted terrigenous and calcareous sandy mud, with numerous fibres of *Posidonia australis* and fragmentary molluscs (e.g. *Spisula* sp., *Phasianella* sp., *Cantharidus* sp., *Dosinia* sp. and *Batillaria* sp.) and foraminifera. Its thickness varies from greater than 4 m in the present subtidal zone but thins inland underlying intertidal and supratidal sediments to between 0 and 2 m, depending on undulations in the surface of the underlying Pooraka Formation. The landward extent of this facies indicates that much of the present coastal environment was a shallow marine environment during the early to mid Holocene.

The intertidal sandflat facies is a grey to light grey,

poorly sorted, terrigenous and calcareous shelly muddy sand. It occurs extensively inland beneath much of the study area having developed in response to upward shoaling of the subtidal sedimentary environment. In most of the Port Pirie region, the intertidal sandflat facies is overlain by samphire facies. This is in contrast to the present-day tidal zonation where a transition from sandflat to mangrove woodland generally occurs.

The intertidal mangrove facies consists of brown or bluish grey, mostly noncalcareous sediments with fragments of roots, sheaths and fibres. It is largely restricted to the present-day distribution of mangrove woodlands, i.e. progradational development and preservation of strata have been limited and *Avicennia marina* var. *resinifera* woodlands appear to have developed in relatively recent times. Where it is undeveloped, modern mangrove roots penetrate into the underlying facies.

The sediment facies of the samphire flat forms a thin veneer over extensive areas of sandflat facies of the coastal plain. It consists of pale brown to light grey, often mottled calcareous and terrigenous clay-rich muds with occasional small gastropods, bivalves and foraminifera. Small plant fibres and thin tubular roots are apparent in some regions but absent in others, depending on whether plant matter was originally present and/or preserved. Gypsum content is variable, due largely to elevation and evaporation history, with gypsarenite dune sediments preserved at the highest elevations of the supratidal zone. There is little distinction between intertidal and supratidal samphire sediment facies, and the two are considered to form a single unit. While particular samphire species can be identified growing in either the intertidal or supratidal zone, in the subsurface, samphire rootlets and remains cannot be identified to species level.

In addition to the sediment facies above, several microenvironments or subfacies occur in the region that have contemporary analogues. In particular, pockets of cyanobacterial facies are evident throughout the intertidal to supratidal zones. Wherever cyanobacterial mats are present in the

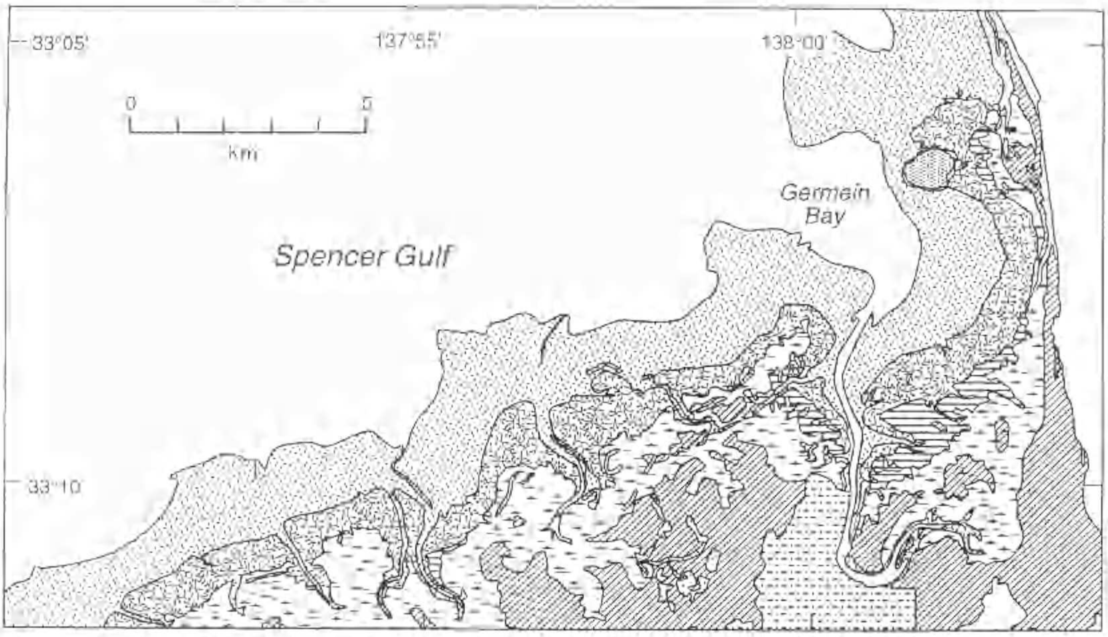

Fig. 8. Coastal geology map of the Port Pirie area compiled from the South Australian Geology Database, Mines and Energy Resources South Australia.

intertidal or supratidal zone there are active sites of sediment aggradation. In the intertidal zone, storm ridge facies, or cheniers when developed over muddy sediments, have been formed during periods of combined high or king tides and storm events. Ridges are generally aligned parallel to the shoreline. Only one storm ridge is preserved in the western Port Pirie area, although several others occur to the east. The northerly orientation of the coastline generally protects the area from dominant southeasterly storm-ridge forming events.

Palaeosea-level indicators

The special significance of the northern Spencer Gulf is that the peritidal coastal succession contains a well-preserved record of palaeosea-level change. The sediments include various palaeosea-level indicators that have been used, with appropriate elevation data, to reconstruct palaeosea-levels. Although present-day tidal environments and equivalent sediment facies may range over significant vertical elevations, the contact between each sediment facies is generally more restricted. Subsurface facies contacts can provide relatively precise estimates of palaeosea-levels, given accurate surveying of the vertical extent of present sedimentary facies and their contacts. Once the elevation range of a particular sedimentary contact is known, a height correction for that contact can be made relative to present sea level. This establishes the elevation at the time of deposition and indicates whether sea level has subsequently risen or fallen.

We have established that, in the Port Pirie area, the boundary between *Posidonia* facies and overlying shelly intertidal sandflat facies provides a palaeosea-level datum corresponding to an upper limit of 0.25 ± 0.25 m TD (Fig. 9). Consequently, the subsurface occurrence of distinctive, massed, fibrous *Posidonia* facies in land-based sediments at elevations higher than 0.25 ± 0.25 m TD implies that relative sea level was previously higher than at present.

In a similar fashion, the intertidal sandflat facies generally occurs between 0.25 and 2.2 m TD relative to present-day sea level. However, a more precise palaeosea-level estimate is provided by the sharp contact between intertidal sandflat facies and overlying mangrove facies that equates to 1.32 ± 0.2 m TD (Fig. 9). At Port Pirie, the mangrove facies mostly occurs directly beneath the present mangrove woodland, and confidence in using its contact with the top of the sandflat facies is greatest where

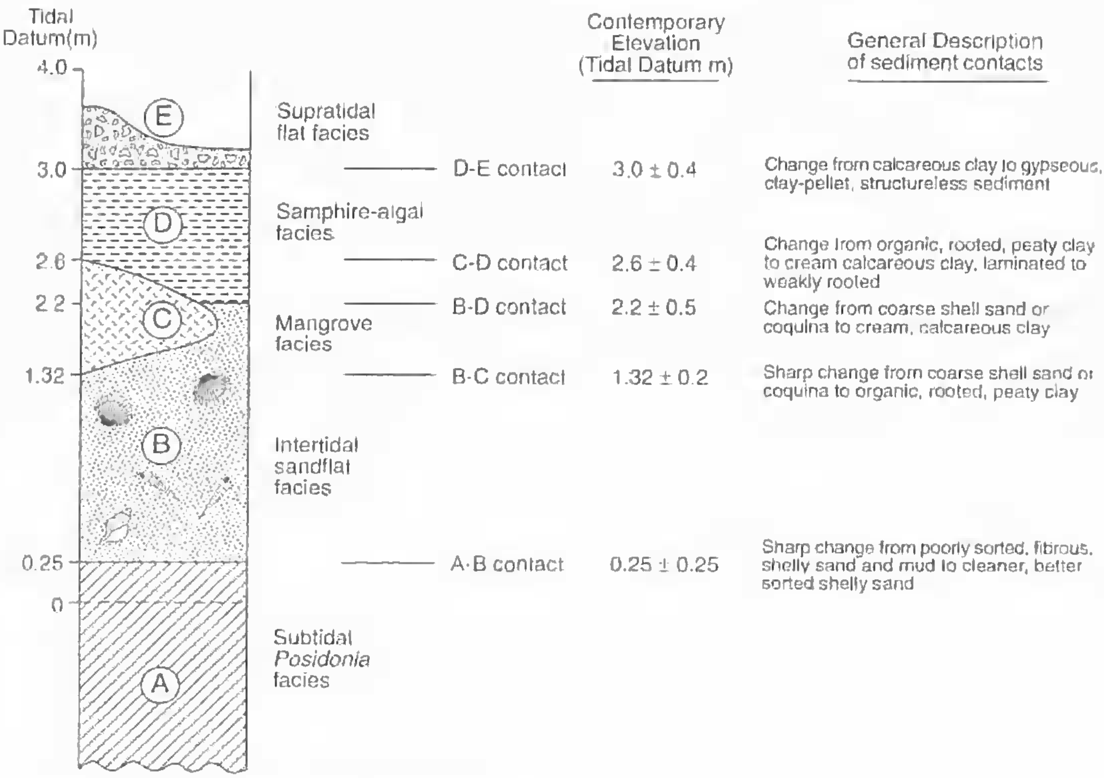

Fig. 9. Palaeosea-level criteria for the Port Pirie coastal region.

massed articulated valves of *Anapella cycladae* and *Katelysia scalarina* or *K. peronii* are present, indicating *in situ* post-mortem preservation. Where the mangrove facies is absent, the contact between the sandflat and samphire facies is also sharp, although the present-day boundary between the intertidal sandflat and samphire zones is not well defined in the immediate vicinity of Port Pirie. The upper limit of the sandflat facies with samphire facies occurs around 2.2 ± 0.5 m TD (Fig. 9).

While the present Port Pirie tidal zones exhibit a transition from mangrove woodlands to samphire marshes at 2.6 ± 0.4 m TD, this is not commonly observed in the subsurface sediments due to the lack of progradational development of this stratigraphic horizon. Consequently, the level at which the samphire facies occurs in the subsurface provides only an approximate estimate of palaeosea-level relative to its present elevation range of 2.2 to 3.0 m TD. Although different samphire species are closely related to small elevation changes, these are not observed at the macro-level in the subsurface.

Discussion

Several factors must be addressed when interpreting the evidence for palaeosea-level change from prograding peritidal sequences. In particular, the relationship of each indicator to sea level at the time of its formation must be established. At Port Pirie, the subsurface presence of *in situ* fibrous remains of the seagrass *Posidonia australis* indicates that sea level was above this site at the time of deposition. The transition between *Posidonia* facies and overlying intertidal sandflat facies is a more powerful indicator of palaeosea-level, corresponding to 0.25 ± 0.25 m present-day TD. Similarly, mangroves grow within a fairly broad intertidal range, but their contact with the intertidal sandflat facies provides a datum of 1.32 ± 0.2 m. Mangroves have previously been cited as one of the more reliable fixed, *in situ* palaeosea-level indicators (Hopley & Thom 1983; Thom & Roy 1983). For northern Spencer Gulf, Burne (1982) reported a range in the elevation of seaward mangrove colonisation from 1.5 to 2.9 m TD (-0.4 to 1.0 m AHD) and as previously mentioned, we record a lower level of mangrove colonisation at 1.32 ± 0.2 m TD. Clearly, the level of seaward colonisation of mangroves depends primarily on local coastal dynamics or coastal orientation, and will occur at a variety of elevations relative to the tidal spectrum (Allen 1995). Therefore, it follows that the height of the contact between sandflat and mangrove facies will also vary. It is apparent from the differences in elevation that the use of mangroves as palaeosea-level indicators can only be applied locally, where present-day elevations of mangrove seaward growth are well defined. Even in this case, the palaeoenvironment may have differed from the modern environment, producing different tidal ranges and mangrove distributions.

The boundary between sandflat and either mangrove or samphire facies has the potential to define palaeosea-level, particularly since its contact in the subsurface is sharp. However, the conundrum at Port Pirie is that while the present-day zonation from sandflat to mangrove woodland is extensive, this transition is not easily observed in the subsurface. Furthermore, while the present-day transition between sandflat and samphire zones is not well represented at Port Pirie, this contact in subsurface sediments is widespread. Near Port Pirie, the present elevation of the sandflat/samphire boundary is 2.2 ± 0.5 m TD. To the northeast at Telowie Beach, this boundary occurs at 2.5 ± 0.3 m TD, a slightly higher elevation than for Port Pirie possibly due to local geomorphic factors and sedimentary processes in the lee of Weeroona Island (Fig. 1). The elevation of the top of the sandflat varies depending on whether it is succeeded by mangroves or samphire. Thus, although the contact can be used as a determinant of sea-level change, there is a wide range in its elevation. This problem may be minimised by careful field surveying of the local region.

Beach ridges and the top of *Posidonia* seagrass deposits are relatively good indicators of palaeosea-levels. However, as with mangroves, beach ridge elevation data cannot be used on a regional basis since the elevations to which such ridges are constructed are highly dependent on local wave regimes. In regard to seagrass as a sea-level indicator, *Posidonia australis* presently grows to 0.25 m TD (-1.68 m AHD) at Port Pirie, but elsewhere in northern Spencer Gulf, an elevation of -0.1 m TD (<-2 m AHD) has been observed (Burne 1982). These differences may be best explained by varying coastal orientation, wave regime and coastal circulation patterns. Although a shore-parallel zonation of sediments and vegetation is common throughout the northern gulf, each sediment and floral or faunal community, whether *Posidonia*-dominated seagrasses, *Anapella* or *Katelysia* sp. bivalves, mangroves or halophytes and saltbushes, has a broad regional range in elevation. Hence, it is imperative that local elevation controls and local conditions be used in assessing sea-level data rather than applying regional values.

Given that the elevation range of tidal facies and sea-level indicators can vary, greater accuracy in reconstruction of palaeosea-level is achieved if several different indicators are used. Each indicator, either relational or fixed, will provide evidence that either supports or challenges indicators from other

horizons. By using such an approach, some of the problems associated with tidal indicators, the elevations of which are influenced by local geomorphic and climatic variations, may be reduced. This study indicates that a combination of palaeosea-level indicators from the top of the *Posidonia* facies and the contact between sandflat and either mangrove or samphire facies is the most reliable method for establishing sea-level change in the Port Pirie area.

A further factor to consider in the reconstruction of palaeosea-levels is whether tectonic activity or subsidence, due to sediment compaction, has occurred subsequent to deposition. There is little evidence of local tectonism in the northern Spencer Gulf during the Holocene, but rather, the region has been uplifted in response to isostatic adjustment of the Earth's crust due to eustatic sea-level rise (Belperio 1995). The effects of sediment compaction in the region are less clear. While little compaction has most probably occurred in either the thin veneer of samphire facies or within the sandflat facies, it is feasible that the extensive, muddy, *Posidonia* facies has undergone some compaction. If this has occurred, it would affect elevation corrections relative to present sea level, acting to decrease the apparent height of former palaeosea-levels.

Conclusions

The tide-dominated coastal plain around Port Pirie has resulted from sediment aggradation, coastal progradation and relative sea-level regression associated with slight sea-level fall following stabilisation around 7,000 years BP. It consists predominantly of subtidal *Posidonia* and intertidal sandflat facies. These facies occur throughout the coastal stratigraphy and underlie present-day intertidal mangrove and supratidal samphire zones.

A tidal-vegetation-sediment relationship exists for each of the Holocene facies deposited within the coastal zone. In the upper subtidal zone, *Posidonia australis* dominates the seagrass community and binds the sediment. The intertidal zone is composed of bare or *Zostera*-covered sandflats that are replaced by *Avicennia marina* var. *resinifera* toward the shore. Further landward in the intertidal to supratidal samphire zone, *Halosarcia*, *Sarcocornia* and *Atriplex* communities have become established in between sabkha-like, bare supratidal flats. Associated cyanobacterial mats grow within mangrove, samphire and supratidal environments.

For each sediment facies, biological palaeosea-level indicators are defined by their growth positions in relation to the tide. At Port Pirie, *Posidonia australis* represents the subtidal environment from just above mean low water spring (MLWS) tide (0.25 ± 0.25 m TD) to depths greater than 4 m TD. *In situ* articulated shells such as *Anapella cycladae* and *Katelysia scalarina* or *K. peronii* are representative of the intertidal sandflat environment from 0.25 ± 0.25 m to 1.32 ± 0.5 m TD, and mangrove facies represent deposition between 1.32 ± 0.2 and 2.6 ± 0.4 m TD.

Good precision in palaeosea-level interpretation can be obtained from peritidal sediments that reveal clear and consistent transitions and contacts from one facies to another. This study has established that the transition from *Posidonia* to sandflat facies and the sharp contact between sandflat and mangrove facies are the best palaeosea-level indicators in this environment. The contact between the sandflat and samphire facies can also be used to establish sea-level change, although only in areas where its present elevation can be established. Dangers are apparent in the broader, regional use of facies boundaries due to the often patchy and variable development of different facies along the coast.

The use of tidally-dominated sediment contacts as palaeosea-level indicators depends primarily on an accurate determination of their present-day elevation ranges relative to tidal datum. Our research has demonstrated that in order best to define palaeosea-level, fieldwork must be carried out at the local scale and take into account coastal processes that have been operating over the long or short-term in the region.

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